Egyptian Journal of Anaesthesia

Vol. 41, 2025
ISSN: 1110-1849 (print))
ISSN: 1687-1804 (online)
DOI: 10.21608/EGJA.2025.413564.1190

ORIGINAL ARTICLE

Preoperative Ultrasonographic Evaluation of Caval Aorta Diameter Index as a New Predictor for Hypotension after Induction of General Anesthesia in Geriatric Patients: A Prospective Observational Study

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Objectives Are the assessment of the prognostic performance of preoperative US determination of the inferior vena cava (IVC) collapsibility index (IVCCI) and the index of IVC to the abdominal aorta diameters (IVCD/AAD) for the development of post-induction hypotension (PIH) in elderly patients receiving general anesthesia (GA).

Patients & Methods 105 patients aged >60 years underwent preoperative US determination of ICVCI and IVCD/AAD index. Patients were invasively observed for the systolic blood pressure (SBP) and mean arterial pressure (MAP), and the development of PIH during 15 minutes after induction of anesthesia (Post-induction) using slow intravenous propofol (1.5mg/kg) injection. Fentanyl (1µg/kg) and Cis-atracurium (0.mg/kg) were injected, endotracheal intubation was performed, and anesthesia was maintained with sevoflurane 2%.

Results 58 patients (55.2%) developed PIH (PIH group). SBP and MAP were significantly lower compared to the baseline measures, and in the PIH than in the No-PIH groups. The estimated IVCDs were significantly narrower, while the AAD was significantly wider, and the IVCCI% was significantly higher, but the IVCD/AAD index was significantly lower in patients of PIH group. The IVCCI% (>45%) and IVCD/AAD (≤0.84) predicted the PIH with an accuracy rate of 91.7% and 93.8%, respectively. The IVCD/AAD index showed high specificity (97.6%). The IVCD/AAD demonstrated insignificant superiority in predictive accuracy for PIH.

Conclusion Preoperative IVCCI% and IVCD/AAD can define patients liable for PIH with a high accuracy rate. The IVCD/AAD showed superiority with high specificity and positive predictive value. ROC curve analysis ensured minor prognostic superiority for the IVCD/AAD.

Keywords Collapsibility index, General anesthesia, Inferior vena cava, Post-induction hypotension.
Received: 13 August 2025, **Accepted:** 12 October 2025.

INTRODUCTION

Intraoperative hypotension may be accompanied by several severe postoperative (PO) complications with a higher incidence of PO myocardial injury, acute kidney injury, and stroke[1]. Notably, intraoperative hypotension mostly occurs immediately after the induction of general anesthesia (GA), and is a common event, particularly in elderly patients undergoing surgical procedures under GA[2].

Postinduction hypotension (PIH) is due to the interaction of multiple factors, including non-modifiable factors, patient-specific factors, and chronic medical disorders[3]. The modifiable factors, particularly the type, dosage, and speed of administration of induction agents, maintenance on certain drugs, and the applied induction regimens[4].

Multiple anesthesia induction strategies were tried to reduce the incidence and severity of PIH. Prophylactic titrated-norepinephrine infusion for early prevention of PIH was superior to repeated ephedrine doses as a therapy for PIH[5]. Ciprofol allowed a significant reduction of the incidence of PIH with hemodynamic stability compared to propofol[6]. Remimazolam is associated with less PIH than propofol and improves the incidence of propofol-induced PIH[7].

Regrettably, hypotension was not confined to the operative time but also thereafter. It also occurs during patients' stay in the post-anesthesia care units (PACU). Still, the incidence of PACU hypotension is largely unknown[8].

The reliance on traditional clinical predictive models to identify patients vulnerable to developing PIH is insufficient to handle the complex interaction between modifiable and unmodifiable predisposing factors[4]. Non-invasive hemodynamic parameters, especially the perfusion index, the inferior vena cava (IVC) collapsibility index (IVCCI), and IVC diameters (IVCD), can predict PIH more accurately than the invasively derived parameters[9].

OBJECTIVES

This study aimed to assess the effectiveness of the index of IVCD to the abdominal aorta diameter (IVCD/AAD) as measured by preoperative US as a safe and noninvasive predictor of PIH of GA in elderly patients compared to the IVCCI.

Design:
Prospective diagnostic accuracy study.

Setting:
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Study Sample Size:
Considering the previous documentation by Salama and Elkashlan[10], that the area under the Receiver Operating Characteristic Curve (AUROC) for IVCD: AAD index as a predictor of hypotension was 0.96. The sample size was calculated, using Medcalc software, to be 105 participants, aiming for a study power of 90% with an α-value of 5%.

Trial Registration:
The Ethics Committee, Al-Azhar Faculty of Medicine, approved the study to start in April 2023 with the registration code of 0319 and registered at TRIALX with NCT06155461.

Study Population:
Patients aged >60 years and who were prepared for a surgical procedure under GA were evaluated for enrolment criteria. Preoperative evaluation entailed obtaining the patients' demographic and clinical data, previous medical disorders, types of maintenance therapies for these diseases, indications, and the type of surgery.

Inclusion criteria:
Patients aged older than 60 years, ASA grade <III, body mass index (BMI) <35kg/m^2 of either sex, and scheduled for elective surgeries under GA. Written consent was signed by patients or their nearest relatives before enrollment in the study.

Exclusion criteria:
Exclusion criteria included emergency surgeries, ASA grade ≥III, and BMI >35 kg/m^2, uncontrolled hypertension with systolic blood pressure (SBP) ≥180mmHg, detection of an intra-abdominal mass with the possibility of IVC compression, mental and psychiatric disorders, and refusal to participate in the study. Also, patients who had a difficult airway, abdominal aortic aneurysm, or previous operations, cardiac abnormalities, or autonomic neuropathy, showed failure of visualization of the IVC, or receiving α-blockers were excluded.

Ultrasonographic imaging:
The measurements of the IVC and aorta were obtained in the M-mode scan using a curvilinear (2 to 5MHz) ultrasound transducer connected to the SONOSITE EDGE II. With the patient in the supine position, the transducer was placed longitudinally in the subxiphoid region to acquire images of the IVC as it drained into the right atrium in the sagittal plane. With the probe still in the subxiphoid area and the liver serving as an acoustic window, the maximum and minimum anteroposterior diameters of the IVC were measured just distal to the IVC-hepatic vein junction using M-mode, during expiration and inspiration, respectively. The IVC collapsibility index was calculated with the following formula: IVC collapsibility index= [(maximum diameter on expiration – minimum diameter on inspiration) / maximum diameter on expiration] *100. Next, the abdominal aorta was identified to the left of the IVC, approximately 10mm above the celiac trunk, and its maximum internal anteroposterior diameter was measured during systole. The caval/aorta diameter index was determined by dividing the maximum IVC diameter by the aortic diameter.

Anesthesia Procedure:

Anesthetic procedure was standardized for all patients. Before induction of anesthesia, patients were premedicated with midazolam (1.5mg) and preoxygenated for 3 minutes with no fluid preload. Preoperatively, under local anesthesia, an arterial line was inserted for invasive hemodynamic monitoring. SBP, the mean arterial pressure (MAP), and heart rate (HR) measurements were taken as baseline measures, and every minute for post-induction (PIN) 15 minutes. Anesthesia was induced with slow intravenous (IV) injection of propofol (1.5mg/kg) till loss of verbal contact, and fentanyl (1µg/kg) and Cis-atracurium (0.2mg/kg). An endotracheal tube of internal diameter 7 and 7.5mm, for females and males, respectively, was inserted, and the cuff was air-inflated. Anesthesia was maintained with sevoflurane 2% in an oxygen flow rate of 3L/min. The respiratory rate was adjusted to 10–15 times/min, with a tidal volume of 6–8 ml/kg and end-tidal carbon dioxide of 35–40mmHg. Lactated Ringer's solution was infused at a rate of 2mL/Kg/hour. Anesthesia-related hypotensive events were recorded and were defined as SBP <90mmHg or MAP <65mmHg, or as a ≥30% drop in their baseline measures. Ultrasound measurements of the diameters of the abdominal aorta (AA) and inferior vena cava (IVC), and the IVC collapsibility index (IVCCI) were taken before induction of anesthesia and at 15 minutes PIN. Ultrasonographic measurements were obtained using the Sonosite Edge II (SonoSite Edge II, Bothell, USA) under the supervision of an expert radiology consultant.

Grouping:

According to the frequency of PIH within 15 minutes after induction (PIN), patients who developed PIH were grouped as the PIH group, and those who passed the observation period smoothly, free of hypotension, were collected as the No-PIH group.

Study endpoints:

1. The primary endpoint is the predictability of the IVCD/AAD index and the IVCCI for PIH.

2. The secondary outcome is the significance of the change in the hemodynamic measures from the baseline measures.

Statistical methods:

Quantitative variables were presented as mean and standard deviation (SD), and categorical variables were expressed as frequencies (number of cases) and relative frequencies (percentages). Data were coded and entered using SPSS (Version 26, IBM Corp., Armonk, NY, USA). Intergroup comparisons were done using an unpaired *t*-test, while intragroup comparisons between baseline and follow-up numerical variables were done using a paired *t*-test. Chi-square (χ^2) and Fisher's Exact test were performed to compare categorical data. The ROC curve was constructed, and AUC analysis was performed to define the best cutoff value of IVCD/AAD and IVCCI% for predicting the possibility of PIH. For all the statistical analyses, a *P*-value <0.05 was indicated as a statistically significant difference.

RESULTS

Initial evaluation included 125 patients who were planned to have elective surgeries under GA with endotracheal intubation. Seventeen patients were excluded for refusal to study participation (*n*= 8) or meeting one of the exclusion criteria (*n*= 9). Three patients who had difficult intubation were also excluded, and 105 patients underwent the study protocol. These patients included 45 males (42.9%) and 60 females (57.1%) with a mean age of 63.3±3.9; range 60-81 years and a mean weight of 78.4±4.6. Eighty-four patients (80%) were ASA grade I, and 21 patients (20%) were ASA grade II. Twelve patients (11.4%) were controlled diabetic, 9 patients (8.9%) were controlled hypertensive, and one was controlled diabetic and hypertensive. During a 15-minute observation period after induction of anesthesia, 58 patients (55.2%) developed PIH (PIH group), and 47 patients (44.8%) had a smooth PIN period without PIH (No-PIH group) as shown in Figure (1). No statistically significant intergroup differences were observed as regards enrollment data.

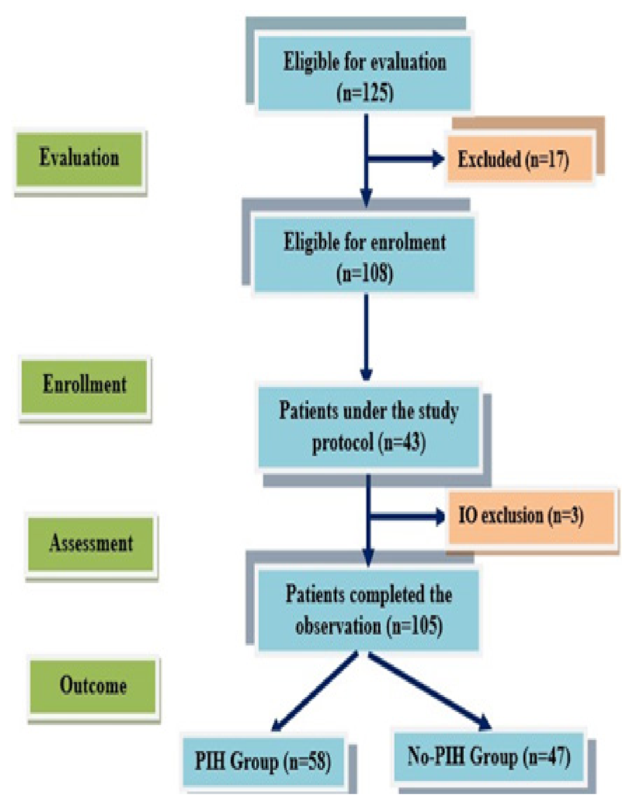

Fig. 1: Patients' flowchart.

Patients of both groups showed progressive decreases in SBP and MAP measurements during 15-minute PIN. The recorded SBP and MAP were significantly lower compared to the baseline measures. At 15-minute PIN, the difference was still significant (*P*<0.001) versus the baseline measures for the respective group. SBP and MAP measures at baseline and 1-minute PIN showed an insignificant intergroup difference. However, the other SBP and MAP measures till 15-minute PIN were significantly lower in the PIH group than in the No-PIH group (Table 1). The recorded HR measures showed insignificant differences compared to baseline measurements till 8 minutes and 7 minutes for groups No-PIH and PIH, respectively. Thereafter, HR measures were significantly lower till the end of the observation period. At 15-minute PIN, HR measurement was significantly (*P*<0.001) lower than the baseline HR. During the observation period, the intergroup differences were insignificant (Table 2).

Table 1: Mean values of SBP and MAP estimated for post-induction (PIN) 15 minutes:

Time of blood pressure estimation Group	Systolic blood pressure (mmHg)			Mean arterial pressure (mmHg)		
	No-PIH	PIH	*P* value	No-PIH	PIH	*P* value
Baseline	126.8±13	128±14.8	0.69	88.3±9.04	90.9±12.7#	0.23
PIN-1	120±9.7#	116.7±14.6#	0.20	85.1±9.4#	83.5±11.3#	0.36
PIN-2	114.3±9.8#	109±12.8#	0.05*	82.2±9.5#	77.2±10.4#	0.01*
PIN-3 (Pre-intubation)	113.5±11.2#	105.7±13.5#	0.001*	80.9±10.9#	73.8±12.2#	0.002*
PIN-4 (Intubation)	119.7±12.3 #	112±14.5#	0.01*	86.1±9.4#	77±11.3#	<0.001*
PIN-5 (post-intubation)	115.2±10.9#	103.2±12.8#	<0.001*	82.2 ±9.4#	75.4±11.8#	0.002*
PIN-6	113.3±10.9#	98.7±10.7#	<0.001*	78.5±9.4#	71.6±6.7#	<0.001*
PIN-7	107.3±9.1#	95.4±8.8#	<0.001*	76.2±9.7#	69.7±8.5#	<0.001*
P1N-8	105.5±7.7#	93.8±7.7#	<0.001*	74.8±8.3#	68.3±6.3#	<0.001*
PIN-9	105.4±6.9#	91.9±7.1#	<0.001*	74.5±8.3#	67.2±7#	<0.001*
PIN-10	102.5±15.9#	90.8±5.9#	<0.001*	73.3±8#	65.2±5.8#	<0.001*
PIN-11	104±6.3#	89.5±4.1#	<0.001*	73.02±7.1#	65.2±5.3#	<0.001*
PIN-12	103.5±6.6#	89.8±7.5#	<0.001*	71.9±5.7#	63.1±5.7#	<0.001*
PIN-13	101.8±5.8#	87.6±4.9#	<0.001*	70.6±6.6#	61.7±4.3#	<0.001*
PIN-14	102±7.2#	83±7#	0.003*	69.6±7.5#	60.5±9.1#	0.01*
PIN-15	102.5±6. 6#	84±0#	0.02*	71±6.4#	58±0#	0.05*
Significance of difference vs. baseline measures	<0.001	<0.001		<0.001	<0.001	

Table 2: Mean HR measurements during post-induction (PIN) 15 minutes:

Time of HR determination Group	No-PIH	PIH	*P* value
Baseline	85.6±10.1	84.5±11.3	0.61
PIN-1	87.1±7.9	85.6±9	0.37
PIN-2	87±7.8	84.7±9.3	0.18
PIN-3 (Pre-intubation)	86.8±7.8	84.5±9.4	0.17
PIN-4 (Intubation)	88.1±8.8	88.3±9.9#	0.93
PIN-5 (post-intubation)	86.4±9.2	85.8±9.9	0.74
PIN-6	86.6±9	85.6±11.3	0.61
PIN-7	84.9±8.5	83.9±10.7	0.63
P1N-8	84.1±8.4	82.1±10#	0.29
PIN-9	82.4±7.2#	81±10#	0.44
PIN-10	82.6±7.1#	80±10.3#	0.19
PIN-11	82.4±6.2#	78.7±10.3#	0.07
PIN-12	82.2±7.9#	77.4±11#	0.08
PIN-13	80.7±8.6#	78.7±10.7#	0.69
PIN-14	81.6±9#	74.5±9.1#	0.31
PIN-15	80.4±9.4#	68±0#	0.23
Significance of difference vs. baseline measures	82.8±12. 1	----	

The estimated IVCDs were significantly (*P*<0.001) narrower, while the AAD was significantly (*P*<0.001) wider in patients with PIH compared to the No-PIH group. The calculated IVCCI% was significantly (*P*<0.001) higher, but the IVCD/AAD index was significantly (*P*<0.001) lower in patients with PIH than in the No-PIH group (Table 3).

Table 3: The preoperative US measurements of the studied patients:

US measures items	Group	No-PIH	PIH	*P* value
IVCD max (cm)	Mean (±SD)	1.73±0.14	1.54±0.18	<0.001*
	Range	1.3-1.93	1.19-1.9	
IVCD min (cm)	Mean (±SD)	1.001±0.13	0.75±0.15	<0.001*
	Range	0.4-1.2	0.5-1.1	
IVCCI %	Mean (±SD)	42±5.6	49.9±4.6	<0.001*
	Range	23-70	38-60	
AAD (cm)	Mean (±SD)	1.74±0.17	1.94±0.16	<0.001*
	Range	1.4-2.05	1.7-2.46	
IVCD/AAD index	Mean (±SD)	0.99±0.07	0.76±0.09	<0.001*
	Range	0.75-1.14	0.63-1	

IVCD: Inferior vena cava diameter; AAD: Abdominal aortic diameter.

At the presumed cutoff points, the IVCCI% and IVCD/AAD might predict PIH with an accuracy rate of 91.7% and 93.8%, respectively. However, the IVCD/AAD index showed higher specificity and PPV than the IVCCI%. At these cutoff points, both variables had high AUCs with a significant (*P*= 0.001) difference compared to the area under the reference line (Table 4; Figure 2, 3). The IVCD/AAD demonstrated better predictive accuracy for PIH, but this difference was not statistically significant (*P*= 0.536).

Table 4: ROC curve analysis for IVCD/AAD and IVCCI% for prediction of post-induction hypotension:

	Cutoff value	AUC(CI)	SE	Sensitivity	Specificity	PPV	NPV	Accuracy	*P*-value
IVCD/AAD index	≤0.84	0.954(0.913-995)	0.021	90.7%	97.6%	98%	89.1%	93.8%	0.001
IVCCI%	>45%	0.934(0.876-993)	0.03	92.6%	90.5%	92.6%	90.5%	91.7%	0.001

AUC: Area under curve; CI: Confidence interval; PPV: Positive predictive value; NPV: Negative predictive value.

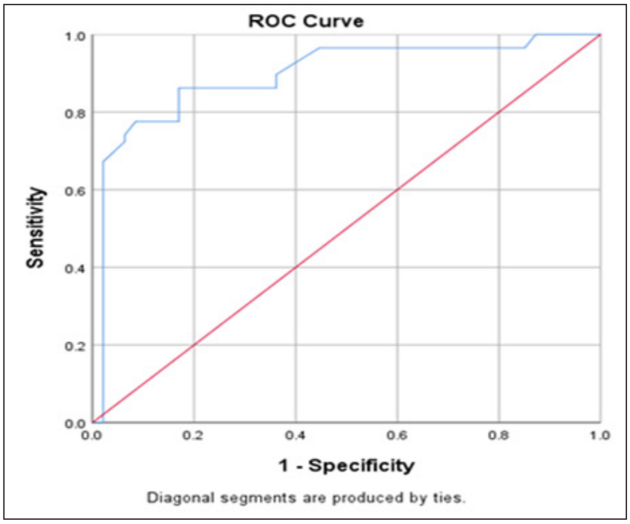

Fig. 2: ROC curve analysis for IVCCI% as a predictor of PIH.

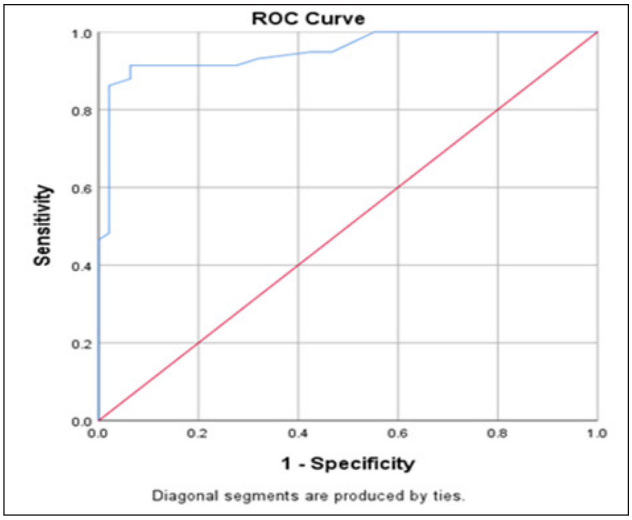

Fig. 3: ROC curve analysis for IVCD/AAD index for prediction of PIH.

DISCUSSION

Comparison of the drugs used for induction of anesthesia showed no remarkable effect on stroke volume index and cardiac index, which remained stable. Thus, PIH appears to result from arterial dilation with reduced systemic vascular resistance rather than venous dilation or reduced myocardial contractility[11].

The US measurement of the IVC collapsibility index and the caval/aorta diameter index both demonstrated high diagnostic accuracy for predicting PIH development and index showed higher specificity and positive predictive values than IVCCI%. However, a comparative study of the diagnostic performance of both methods using ROC analysis found the IVCD/AAD index to be superior to IVCCI%, although the difference in AUCs was not statistically significant.

These findings align with multiple recent studies in various situations. Lal *et al*.,[12] stated that the IVCD/AAD index could significantly predict PIH at a cutoff value of 0.98 with an AUC of 0.635, 75% sensitivity, and 62% specificity. Fathy *et al*.,[13] showed that the IVCD/AAD index could significantly predict PIH in adult patients under GA at a cutoff value of ≤0.84 with 91% sensitivity and 98% specificity. Omar *et al*.,[14] documented that the IVCD/AAD index is a reliable indicator of PIH during GA.

Thereafter, Yang *et al*.,[15] found that IVC measures and the IVCD/AAD index can predict volume reactivity and persistent post-spinal anesthesia hypotension (PSAH); however, the IVCD/AAD index is a more reliable parameter for both purposes. Chaudhary *et al*.,[16] found that collapsibility indices for the subclavian vein and IVC have good and comparable diagnostic accuracy for the prediction of PIH, with a significant positive correlation between both parameters. Sharma *et al*.,[17] recommended the use of preoperative estimations of the left ventricular outflow tract velocity time integral or IVCCI to predict PIH and to decrease the morbidity of patients undergoing surgery.

Liu *et al*.,[18] reported an incidence of 45.1% for PSAH, and ensured that the variability of the IVC and SBP were independent risk factors for PSAH. The ROC curve showed a higher AUC for IVCCI at a cutoff point of >37.5% than that for SBP at a cutoff point of >157mmHg. Liu *et al*.,[18] also found that the combination of IVCCI% and SBP had a better predictive value with a higher AUC value than each variable alone, and concluded that high preoperative SBP and IVCCI may help guide to provision of personalized treatment for patients assigned to receive SA. Further, Liu *et al*.,[19] in a systematic review documented that preoperative US indices for IVC and the carotid artery corrected flow time are reliable predictors for PIH. Another systematic review concluded that IVCCI is a strong predictor of PIH, and 40-45% is recommended as a cutoff point for the diagnostic assessment of IVCCI[20].

Moreover, Zhou *et al*.,[21] detected a 48.3% frequency of hypotension after propofol induction and found that pre-induction IVCCI at a cutoff point of >38.25% could predict PIH with an AUC of 0.72, indicating a strong correlation between IVCCI and the maximum percentage drop in mean blood pressure after propofol induction. Additionally, Eeshwar *et al*.,[22] reported a PSAH incidence rate of 33%. ROC analysis revealed better sensitivity and specificity for the IVCD/AAD index than for the IVCCI, and concluded that the IVCD/AAD index might be used to predict volume status and guide the co-loading protocol during spinal anesthesia.

The reported minor diagnostic inferiority for the IVCCI% might be attributed to the fact that the IVC, as a high capacitance vessel with good sensitivity to changes in the volume status, its diameters can differ greatly with patients' age and constitutional parameters[23]. Additionally, IVCCI depends mainly on the intrathoracic and intra-abdominal pressures that might be affected by many pathophysiological causes; standardizing the IVCCI to the AAD might improve the validity of the measures[24].

CONCLUSIONS

The obtained results allowed concluding that preoperative IVCCI% and IVCD/AAD can point out patients who were vulnerable to developing PIH with a high accuracy rate. The IVCD/AAD showed superiority with high specificity and positive predictive value. ROC curve analysis ensured minor diagnostic superiority for the IVCD/AAD with a weak significance level.

LIMITATIONS

The small sample size and the fact that the study was conducted at a single center are limitations in determining the accuracy and applicability of the study outcomes.

RECOMMENDATIONS

Multiple multicenter randomized controlled studies are required to reassess the utility and the performance of the applied procedure and to settle the outcomes.

CONFLICT OF INTERESTS

There are no conflicts of interest.

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